DEVELOPMENT OF SUSTAINABLE MATERIAL FOR HYBRID WALL SYSTEM TO IMPROVE INDOOR THERMAL PERFORMANCE

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To my lovely mother and amazing father. I couldn’t have done this without you. I believe that this achievement will complete your dream that you had for me all these many years ago when you chose to give me the best education you could.

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ABSTRACT

Thermal performance of building envelope has been of great importance in determining the indoor thermal environment mainly due to the impact of existing global warming issues. Due to the hot and humid climate of Malaysia, and poor thermal design of building envelope, mechanical cooling of buildings is becoming almost a necessity. This necessity in the case of low-income home owners is an added burden. Thus there is a need to provide wall system with better thermal performance than conventional wall systems. Due to the emphasis on developing sustainable built environments, researchers are striving for waste incorporation in building wall material. However, the waste incorporated within the building wall system, especially in bricks still lacks practical applicability when it comes to the overall performance of the system in terms of mechanical, thermal and physical properties. The focus of the research is to tackle the twin issues of sustainability and thermal performance of building wall systems for affordable homes using a Design Science methodology. A cost-effective sustainable alternative building wall system with better thermal performance than conventional material is proposed by utilizing locally available waste materials such as waste glass and oil palm industry byproducts. The enhancement of thermal performance of wall materials was done by the introduction of cellular porous palm oil fibers to lower the heat transfer. Fiber reinforced mortar (FRM) and thermally enhanced sustainable hybrid (TESH) bricks were developed by optimizing the mix design using Glass Powder, Palm Oil Fly Ash and Oil Palm Fibers based on Taguchi's Process Parameter approach. Both the FRM and TESH bricks, which constitute the thermally enhanced sustainable hybrid (TESH) wall system, were analyzed for physical, mechanical and thermal performance and they comply with the various codes of practice for building materials. ANSYS WORKBENCH software was used to determine the thermal performance of the newly developed TESH. The temperature distribution and rate of heat transfer through the wall system was found to be significantly lower than conventional wall systems. Also, comparative energy analysis established that the energy consumption is 10.6 % lower for TESH. Due to the lower electricity consumption, the total energy costing for the building

was also reduced by 10.2 %. Thus, TESH proves to be more sustainable and cost effective within the operational phase of the building. TESH is a sustainable alternative for low-cost housing units due to its proven low embodied energy as it comprises mainly of locally available waste materials for its production.

ABSTRAK

Prestasi terma envelop bangunan adalah amat penting bagi menentukan keadaan suhu udara dalaman bangunan, terutama sekali memandangkan impak pemanasan global. Jenis rekabentuk dinding luar and bumbung bangunan (envelop bangunan) yang tidak menitikberatkan aspek kepananasan dalaman bangunan serta cuaca yang panas dan udara yang lembab di Malaysia memaksa penhuni rumah menggunakan pelbagai alat penyejukan udara. Kos bagi menyejukkan udara dengan peralatan mekanikal menambahkan kos hidup, dan bagi penghuni rumah kos rendah ini akan menjadi suatu beban tambahan. Oleh yang demikian tujuan kajian ini adalah menghasilkan satu sistem dinding berupaya menjamin prestasi terma dalam rumah yang lebih baik berbanding sistem konvensional. Dalam usaha berbuat demikian beberapa penyelidik juga berperihatin mengenai isu kelestarian alam bina dan berusaha untuk menggunakan bahan buangan sampingan industri-industri dalam membina dinding seumpama itu, tetapi prestasi menyeluruh tidak diambil kira. Fokus kajian ini adalah untuk menyediakan satu sistem dinding alternatif yang berprestasi lebih menyeluruh dari segi kelestariannya, berkos efektif dan mempunyai prestai ciri mekanikal yang dapat meningkatkan prestasi terma bahagian dalaman rumah kos rendah. Bahan-bahan buangan tempatan yang sedia ada digunakan berdasarkan pendekatan “Taguchi’s Process Parameter Approach”, bagi menghasilkan campuran daripada kaca sisa dan hasil sampingan industri kelapa sawit menggunakan metodologi “Design Science”. Peningkatan prestasi terma dalam rumah dicapai dengan menggunakan “Oil Palm Fibers” yang mempunyai gentian berliang selular, sebab ia dapat mengurangkan pemindahan haba dalam sistem dinding yang terdiri daripada Fiber Mortar Bertetulang (FRM) dan bata hibrid berlestari terma (TESH). Kedua-dua FRM dan batu bata TESH, yang merupakan Sistem Dinding TESH dianalisis untuk prestasi fizikal, mekanikal dan haba dan ia dikenalpasti mematuhi kod amalan piawai. Sistem dinding TESH dianalisis untuk pemindahan haba menggunakan perisian ANSYS WORKBENCH. Taburan suhu dan kadar pemindahan haba melalui sistem dinding didapati lebih rendah daripada sistem dinding konvensional. Analisis perbandingan tenaga membuktikan bahawa sistem dinding TESH mempunyai prestasi lebih tinggi dalam mengurangkan suhu ruang dalaman rumah berbanding sistem dinding biasa dan terbukti adalah lebih mampan berdasarkan analisis yang dilakukan pada fasa operasi bangunan. Tenaga yang digunakan oleh sistem dinding TESH adalah 10.6% lebih rendah dan kos tenaga kurang sebanyak 10.2%; maka ia terbukti boleh menjadi alternatif yang mampan untuk mencapai keselesaan terma untuk unit rumah kos rendah secara lebih berkos efektif.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

Al_2O_3	-	Aluminium oxide
ANOVA	-	Analysis of variance
ASHRAE	-	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BEM	-	Boundary element method
$CaCO_3$	-	Calcium Carbonate (Calcite)
CaO	-	Calcium Oxide
CAS	-	Calcium alumina silicates
C-A-S-H	-	Calcium alumino silicate hydrate
Cl	-	Chlorine
CO_2	-	Carbon dioxide
CO_2e	-	Carbon dioxide equivalent
Cp	-	Heat Capacity (J/g.ºC)
C_{pw}	-	Heat capacity of water (J/g.ºC)
Cr_2O_3	-	Chromium oxide
C-S-H	-	Calcium silicate hydrate
CSIRO	-	Scientific and Industrial Research Organization
D	-	Diameter (m)
DOF	-	Degree of Freedom
DSR	-	Design Science Research
e	-	Thermal Effusivity ($WK^{-1}m^{-2}\ s^{1/2}$)
EE	-	Embodied energy
EFB	-	Empty fruit brunch
EPA	-	Environmental Protection Agency
FDM	-	Finite difference method
Fe_2O_3	-	Iron oxide or Ferric oxide
FEA	-	Finite element analysis
FEM	-	Finite element method

FRM	-	Fibre reinforced mortar
GBS	-	Green building studio
GHG	-	Greenhouse gas
GP	-	Glass Powder
HVAC	-	Heating Ventilation and Air Conditioning
IAQ	-	Indoor Air Quality
IEA	-	International Energy Agency
IPCC	-	Intergovernmental Panel on Climate Change
IRA	-	Initial rate of absorption
K_2O	-	Potassium oxide
k-value	-	Thermal Conductivity (W/m.K)
L	-	Length (m)
LCH	-	Low Cost Housing
LCTH	-	Low Cost Terrace Housing
LOI	-	Loss of Ignition
M	-	Rate of flow of water (kg/s)
MgO	-	Magnesium oxide
Mn_2O_3	-	Magnesium oxide
MSW	-	Municipal solid waste
Na_2O	-	Sodium oxide
NaOH	-	Sodium hydroxide
OPC	-	Ordinary Portland Cement
OPF	-	Oil Palm Fibers
OPS	-	Oil palm shell
P_2O_5	-	Phosphorous pentoxide
POFA	-	Palm oil fly ash
q	-	Amount of heat transfer per unit area
Q	-	Amount of heat transfer
R-Value	-	Thermal Resistance
S/N	-	Signal to noise ratio
SEM	-	Scanning electron microscopy
ρ	-	Bulk Density (kg/m^3)
SHGC	-	Solar Heat Gain Coefficient
SiO_2	-	Silicon dioxide (Silica)

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